The Spacecraft Design Process

John Ledyard

Caltech

March 2, 2000

Introduction

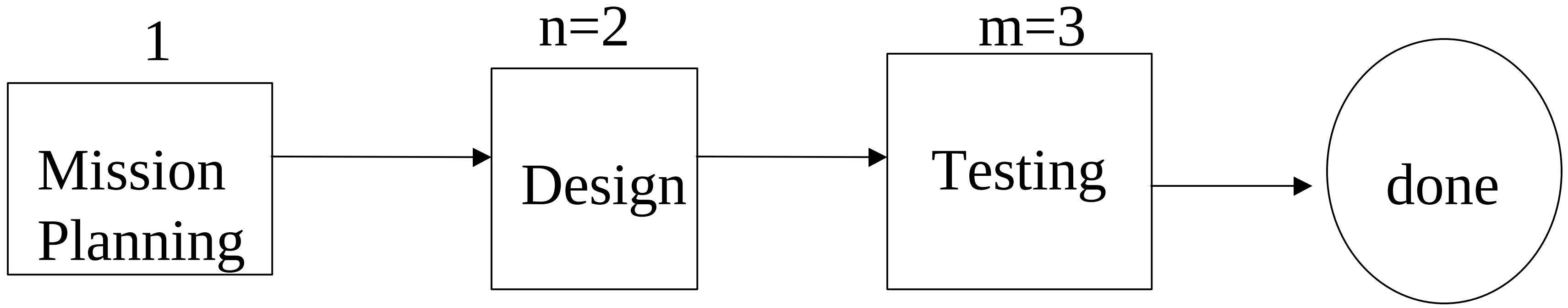
- The majority costs of spacecraft design are personnel and not hardware.
- Personnel costs are time related.
- Cycle time to design and test a spacecraft is highly variable (6 months to 4 years).
- Therefore it is important to understand the determinants of cycle time to understand costs

Introduction

- The major determinants of cycle time are:
  - Technical difficulty
  - Team effectiveness
  - Concurrency
- The goal is to model these in a measurable way to get at the cost/time tradeoff.

In a perfect world

- Mission planning, design, testing

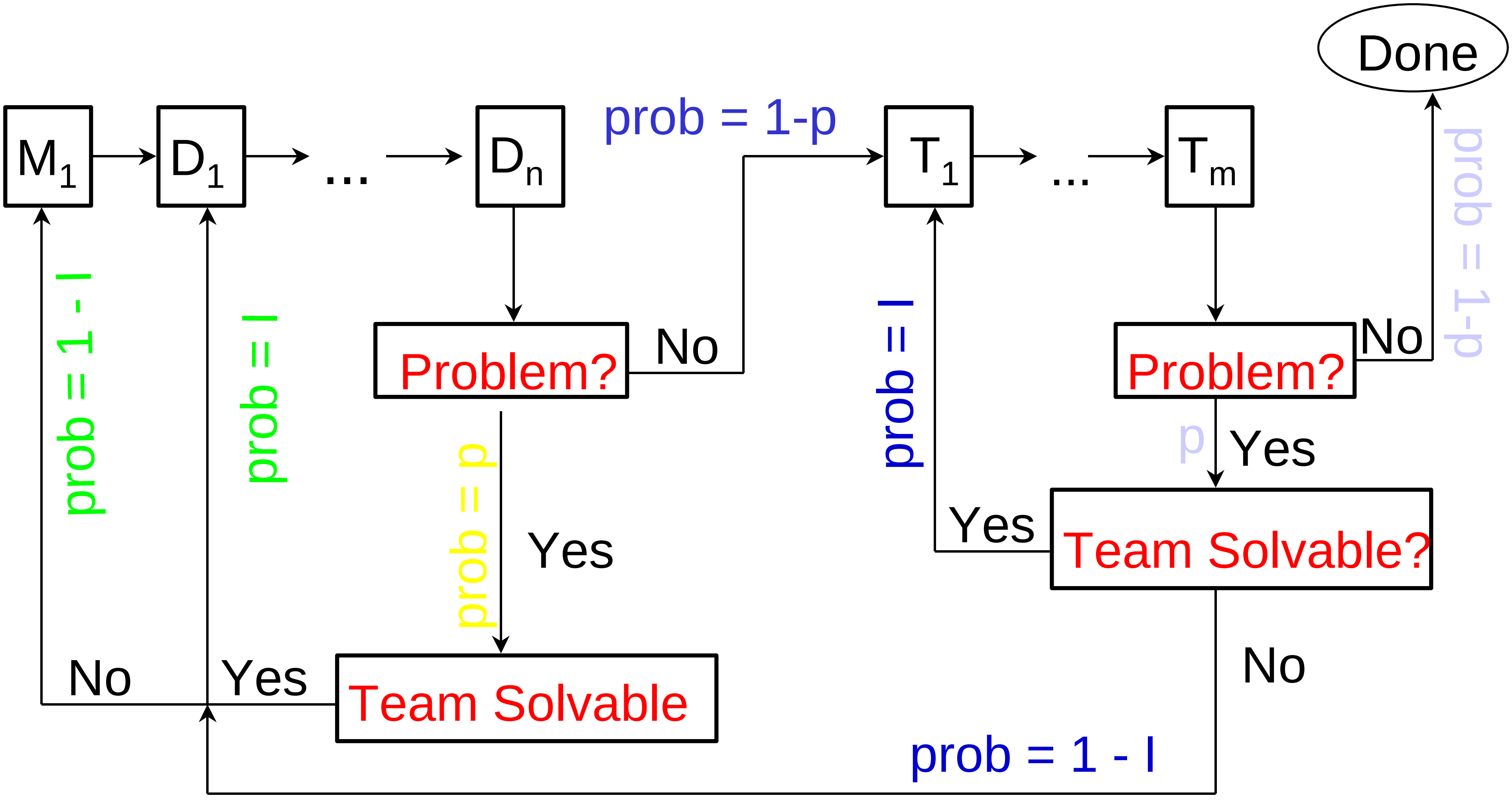


- Expected time = 1 + n + m

Add some reality

- Complexity of the problem
  – The probability that unanticipated problems occur
- Efficiency and innovativeness of the team
  – The probability the team can solve the unanticipated problems easily
- Concurrency
  – The probability one can begin testing earlier in the design phase

Complexity of Problem (p)



EQUATIONS

$E_0 = (1\text{-}p)(E_1 + n+1) + pI(E_0+n) + p(1\text{-}I)(E_0+n+1)$

$E_1 = (1 - p)m + pI(E_1+m) + p(1\text{-}I)(E_0+m-1)$

Solving for E_0, the solution is:

$E_0 = (m\text{-}p)/1\text{-}p + (n+1)(1\text{-}pI)/(1\text{-}p)^2 + p^2I(1\text{-}I)/(1\text{-}p)^2$

Example numbers

- n=2, m=3
  - Minimum cycle time = 6 months
- p=3/4 (relatively hard project)
- If I=1/5 (inefficient team), E_o=48.36
  - Approximately the time for Pathfinder
- If I=1/2, E=36.75 (a 24% decrease).
- If I=4/5, E=26.76 (a further 27% decrease)

Concurrency and Difficulty

Concurrency is measured with two parameters:

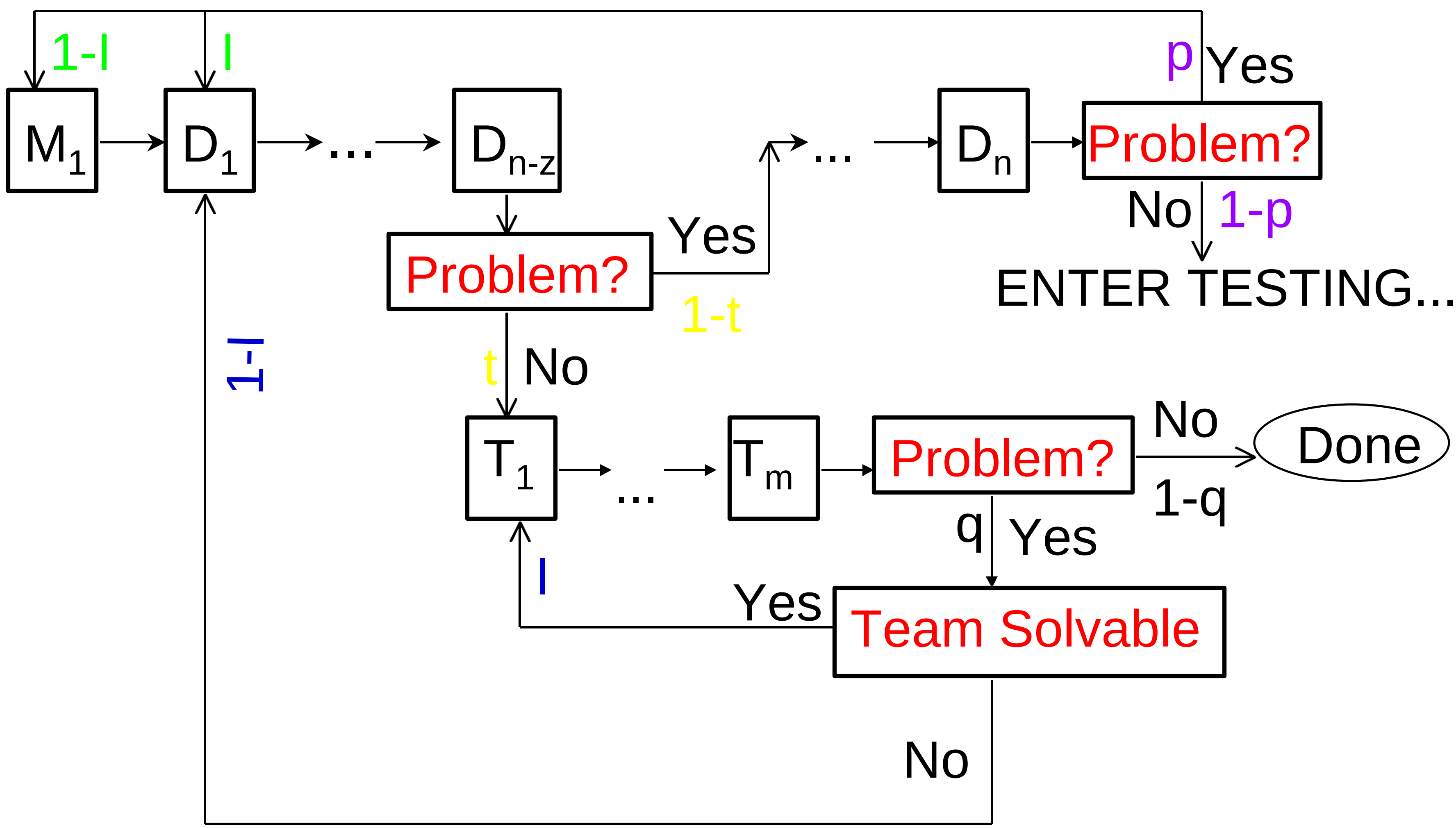
① z

- n-z number of stages earlier testing begins

② q

- probability that a problem occurs after early testing

Concurrency (z, t,q)



EQUATIONS

We redefine E_0.

$$E_0 = 1+E_2$$

$$E_1 = (1 - q)m \ + qI(E_1+m) + q(1-I)(E_0+m-1)$$

$$E_2= t(E_1+n-z)+(1-t)[n+(1-p)(E_1)+pIE_2+p(1-I)(E_0)$$

$$= (E_1+n-z)(1-p+tp) + (1-t)p\ [z/p + n - z +IE_2$$

$$+ (1-I)E_0]$$

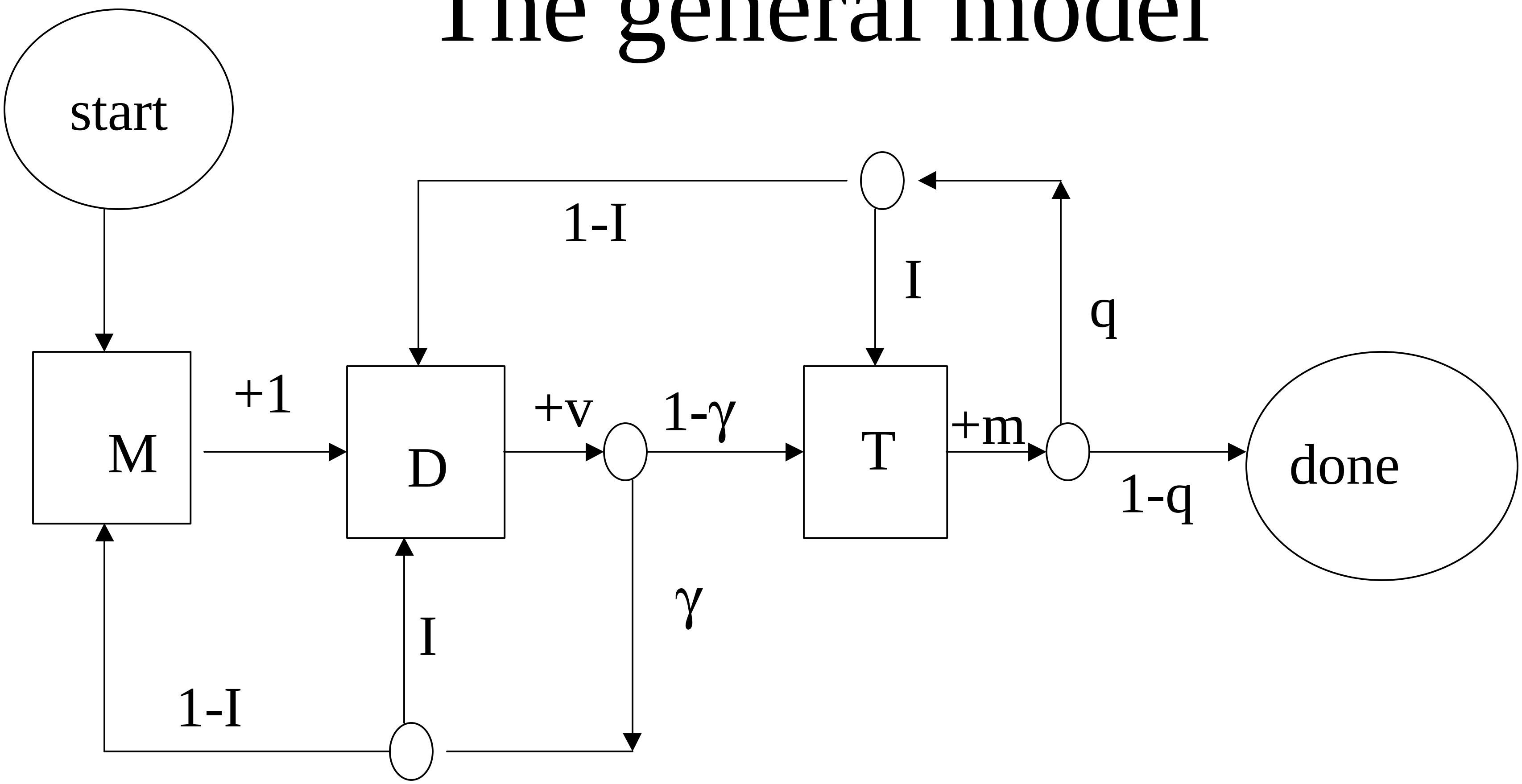
SPECIAL CASE

When n=2, m=3, p=q=3/4

	I=0	I=1/5	I=1/2	I=4/5	I=1
t=0	**57**	**48.4**	**36.8**	**26.8**	**21**
t=1/5	**37**	**32.4**	**26.1**	**20.7**	**17.5**
t=1/2	**25**	**22.8**	**19.8**	**17**	**15.4**
t=4/5	**19.4**	**18.3**	**16.8**	**15.3**	**14.4**
t=1	**17**	**16.4**	**15.5**	**14.6**	**14**

Value of E_o in months

The general model



Expected time to complete = E_o = $\dfrac{m-q(1-I)}{1-q}+\dfrac{[1-qI](v+1-gI)}{(1-g)(1-q)}$

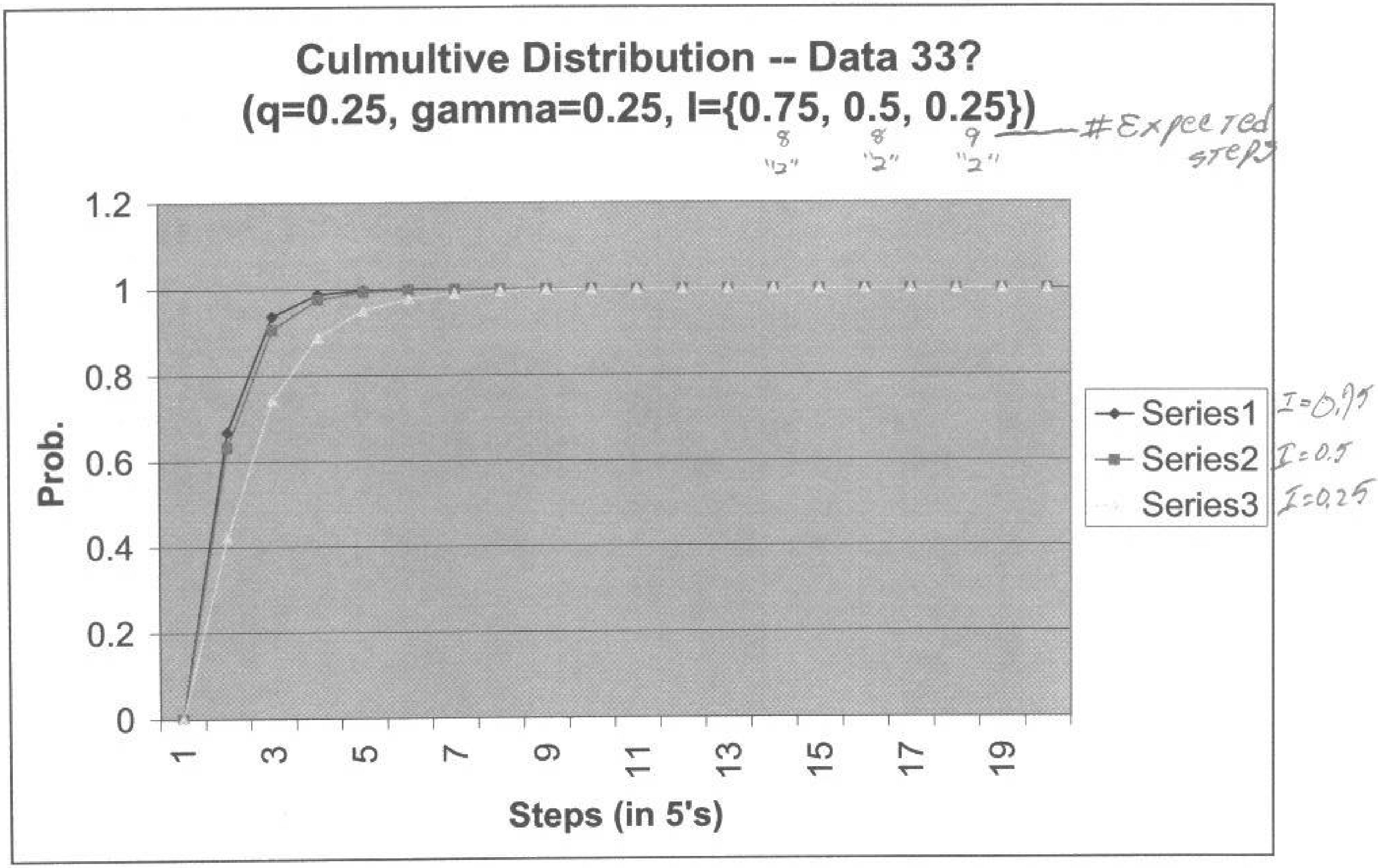
The general model

- v,m, and gamma are mixed measures of difficulty, concurrency and the height of the "ready to test" bar
- $0<I<1$ is a measure of team effectiveness
- $0<q<1$ is the probability of failing testing
  - q and (v,gamma) are inversely related

Time to Complete Simulations

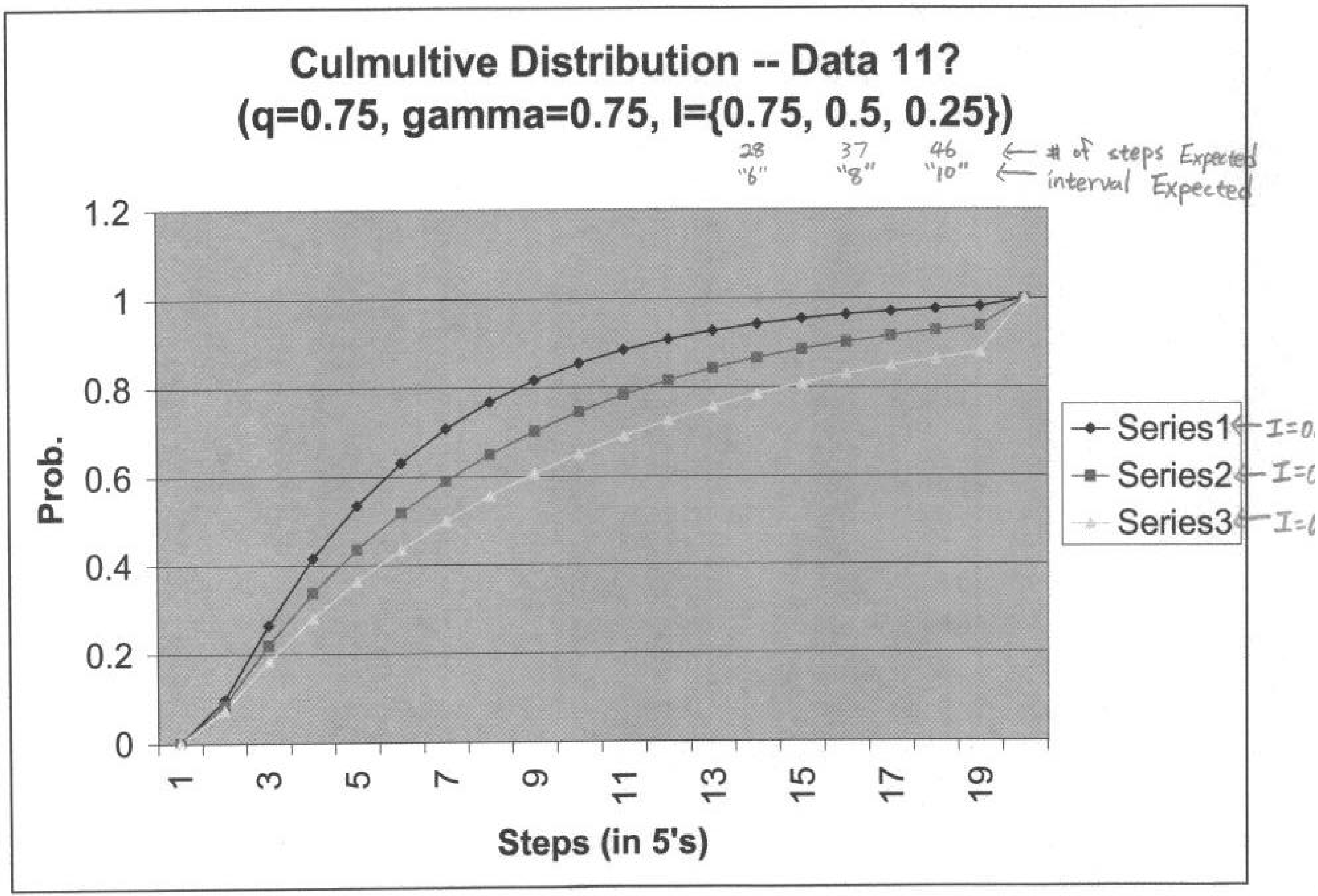
- Would prefer explicit solution but for now…
- Monte-Carlo study
- Two cases
  - Easy project, low testing target
  - Hard project, high testing target

9



Culmultive Distribution -- Data 33?
(q=0.25, gamma=0.25, I={0.75, 0.5, 0.25})
8 "2"
8 "2"
9 "2"
#Expected steps
1.2
1
0.8
0.6
0.4
0.2
0
Prob.
1
3
5
7
9
11
13
15
17
19
Steps (in 5's)
Series1 I=0.75
Series2 I=0.5
Series3 I=0.25

v=2, m=3



Culmultive Distribution -- Data 11?
(q=0.75, gamma=0.75, I={0.75, 0.5, 0.25})
28
"6"
37
"8"
46
"10"
# of steps Expected
interval Expected
Prob.
Steps (in 5's)
Series1
Series2
Series3

Faster/Cheaper Tradeoffs

- Cost functions

  $= C(m,q,I,v,\gamma)$

- Time to complete

  = probability {time through < T)

- Trade-off

  Max Prob {time < T}

  Subject to $C(m,q,I,v,\gamma) < B_o$

Future Work

- Integrate with the Koenig, Smith, Wall work on measuring team effectiveness.
- Integrate with other work measuring the “riskiness” of projects.
- Model the “ready to test” standard
- Solve for explicit solutions for
  - Prob (stop $<$ T)
  - Variance of stopping time